Can CT-Scan Measurements of Humpback Deformity, Dislocation, and the Size of Bony Cysts Predict Union after Surgery for Scaphoid Nonunion?

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Abstract

Objective Scaphoid fractures are associated with high rates of late- or nonunion after conservative treatment. Nonunion is reported to occur in approximately 10% of all scaphoid fractures. It is known that the union of scaphoid fractures is affected by factors such as location at proximal pole, tobacco smoking, and the time from injury to treatment. Same factors seem to affect the healing after surgery for scaphoid nonunion. While the impact of preoperative humpback deformity on the functional outcome after surgery has been previously reported, the impact of humpback deformity, displacement, and the presence of bony cysts on union rate and time to healing after surgery has not been studied.

Purpose The primary purpose of this study is to assess the association of humpback deformity, fragment displacement, and the size of cysts along the fracture line with the union rate and union time, following surgery of scaphoid nonunion. The second purpose of the study is to investigate the interobserver reliability in the evaluation of computed tomography (CT) scans of scaphoid nonunion.

Patients and Methods From January 2008 to December 2018, 178 patients were surgically treated in our institution. After exclusion criteria were met, 63 patients with scaphoid delayed- or established nonunion, and preoperative CT scans of high quality (<2mm./ slice), were retrospectively analyzed. There was 58 men and 5 women with a mean age of 30 years (range: 16–72 years). Four orthopaedic surgeons and one radiologist independently analyzed the CT scans. The dorsal cortical angle (DCA), lateral intrascaphoid angle (LISA), the height-to-length ratio, the size of the cysts, and displacement of the fragments were measured. Healing was defined by CT scan, or by conventional X-ray, and status of no pain at clinical examination. Thirty-two of the patients had developed nonunion (>6 months postinjury), while 31 were in a stage of delayed union (3–6 months postinjury).

Keywords
- scaphoid nonunion
- humpback deformity
- scaphoid dislocation
- scaphoid cyst
- CT scan measurements

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Results Open surgery with cancellous or structural bone graft was the treatment of choice in 49 patients, 8 patients were treated with arthroscopic bone grafting, and 6 patients with delayed union were operated with percutaneous screw fixation, without bone graft. Overall union rate was 86% (54/63) and was achieved after 84 days (12 weeks) (mean). The failure rate and time to healing were not associated with the degree of the humpback deformity, size of the cysts, or displacement of the nonunion in general. However, greater dislocation, and the localization of the nonunion at the scaphoid waist, showed significant influence on the union rate. Dislocation at nonunion site, in the group of the patients who united after surgery, was 2.7 mm (95% confidence interval [CI]: 1.5–3.7), and in the group who did not unite was 4.2 mm (95% CI: 2.9–5.7); $p = 0.048$). Time from injury to surgery was significantly correlated with time to union ($p < 0.05$), but not associated with the union rate ($p < 0.4$). Patients treated arthroscopically achieved faster healing (42 days), (standard deviation [SD]: 22.27) as compared with patients treated by open techniques (92 days; SD: 70.86). Agreement among five observers calculated as intraclass correlation coefficient was for LISA: 0.92; for height-to-length ratio: 0.73; for DCA: 0.65; for size of cysts: 0.61; and for displacement in millimeters: 0.24, respectively.

Conclusions The degree of humpback deformity and the size of cysts along the fracture line of scaphoid nonunion have no predictive value for the result, neither for the union rate nor the union time after surgery for the scaphoid nonunion. However, larger dislocation of the fragments measured at the scaphoid waist showed lower union rate. Time to healing following surgery is mainly influenced by the time from injury to the surgical treatment and may be influenced by the choice of the surgical technique. Interrater reliability calculation was best with LISA measurements, and worse with the measurements of the dislocation.

Level of Evidence This is a Level III, observational, case–control study.

Fracture of the scaphoid bone is the most common fracture of the carpal bones. Reported incidences are 100–150/100,000 per year for male population and 15–50/100,000 per year for female population.[1–3] Injuries occur mostly in young, active, urban, male individuals. The most common localization of the fracture is the waist (64–66%), hereafter, the distal pole (25–31%), and then the proximal pole (5–10%). Scaphoid waist fractures are often nondisplaced with a good prognosis after conservative treatment. However, the risk of nonunion is reported to be approximately 10%, increasing up to 50%, if displacement is more than 1 mm.[4,5] Fractures in the proximal pole have a higher risk of nonunion, as much as 31%, dependent on the treatment.[5,6] The healing process can be complicated by volar translation of the distal fragment, relative to the proximal, creating angulation, and a humpback-like deformity. The presence of humpback deformity will disrupt carpal kinematics of the entire wrist. In some cases, it results in dorsal intercalated segmental instability, causing decreased movement of the wrist, pain, collapse of the carpus, and ultimately, osteoarthritis of the wrist joint.

Although scaphoid nonunion may be asymptomatic, the main goal of the treatment is to achieve union of the scaphoid. Thereby, the purpose of the treatment is to restore the anatomy of the wrist, postponing the occurrence of degenerative changes associated with the natural course of the condition.[7–9] The development of scaphoid nonunion advanced collapse (SNAC) is an irreversible, painful, progressive chronic collapse of the carpal bones. SNAC is diminishing wrist strength and function and should therefore be avoided. In these late stages, when SNAC of the wrist occurs, only salvage operative procedures are recommended, leading to permanent functional impairment of some degree. Thus, surgical efforts have been directed toward the development of surgical techniques, promoting healing of the scaphoid nonunion in the young, active population.

Various treatment options including vascular- or nonvascular grafting,[10–16] by open, arthroscopically assisted,[17–23] or percutaneous techniques,[24–28] have been proposed as methods of choice to treat scaphoid nonunion. It is known that the occurrence of scaphoid nonunion is affected by factors, such as fracture location, displacement, and the time from injury to treatment.[29] Furthermore, healing can be complicated by a humpback deformity, and development of angulation and bony cysts within nonunion site.[30–32] However, the impact of humpback deformity, and bony cysts, on union rate and union time, is believed to have great importance, but the evidence is scarce.[33–36]

Interpretation of the most used angulation measurements could potentially be used as prognostic factors for union after

surgery for the scaphoid nonunion. Displacement and the size of the bony cysts, measured by computed tomography (CT) scan, preoperatively, could equally be used as a tool in the decision-making process, before surgery.

We hypothesize that greater degree of either displacements, angulations, or bony cysts, if present at the nonunion site, is associated with poorer union outcome. As scaphoid nonunion at proximal pole localization[37] seems to be less exposed to angulation, we focus on the localization at scaphoid waist.

Purpose

The purpose of this study is to examine, if the degree of humpback deformity, the fragment displacement, or the size of the cysts along the fracture line is associated with different union rate and union time, following surgery of scaphoid nonunion. Furthermore, the reliability among observers assessing different CT scan measurements is calculated.

Materials and Methods

From January 2008 to December 2018, 178 patients were operated for scaphoid fracture or nonunion at our institution. Inclusion and exclusion criteria for the enrollment in this study are shown in ►**Fig. 1**.

Exclusion Criteria

Acute cases with less than 2 months from injury to surgery, operated for fractures of the scaphoid, were excluded from this study. All patients with the proximal pole localization of the scaphoid nonunion underwent magnetic resonance imaging with gadolinium enhanced contrast preoperatively. If the findings showed evidence of avascular necrosis (AVN) of the proximal pole, patients were treated with vascular grafting techniques, and were excluded from this study. Finally, 91 cases had to be excluded from the study, either due to nonexistent preoperative CT scan ($n = 62$) or due to a poor technical quality of the existing CT scan ($n = 29$). The major technical issue leading to exclusion was too thick slices of the CT scan (>2mm), especially from cases where CT scans were not obtained in our institution. The second technical problem were CT scans where sagittal series were not reconstructed parallel to the axis of the scaphoid but in sagittal forearm axis. Both technical challenges were making the reconstruction of CT scans inaccurate, and the interpretation of the measurements difficult, or even impossible.

Inclusion Criteria

Only cases who had a high-quality preoperative CT scan of the injured scaphoid were included in this study. Preoperative CT scans of high quality (< 2 mm/ slice) reformatted on scaphoid long axis, according to Mallee et al and Cheema et al,[38,39] of the remaining 63 patients were retrospectively analyzed. The cohort was fully representative for this patient population (►**Table 1**).

Population

There was 58 men and 5 women with a mean age of 30 years (range: 16–72). Two patients had a nonunion at the distal part of the scaphoid, 49 at the scaphoid waist, and 12 at the

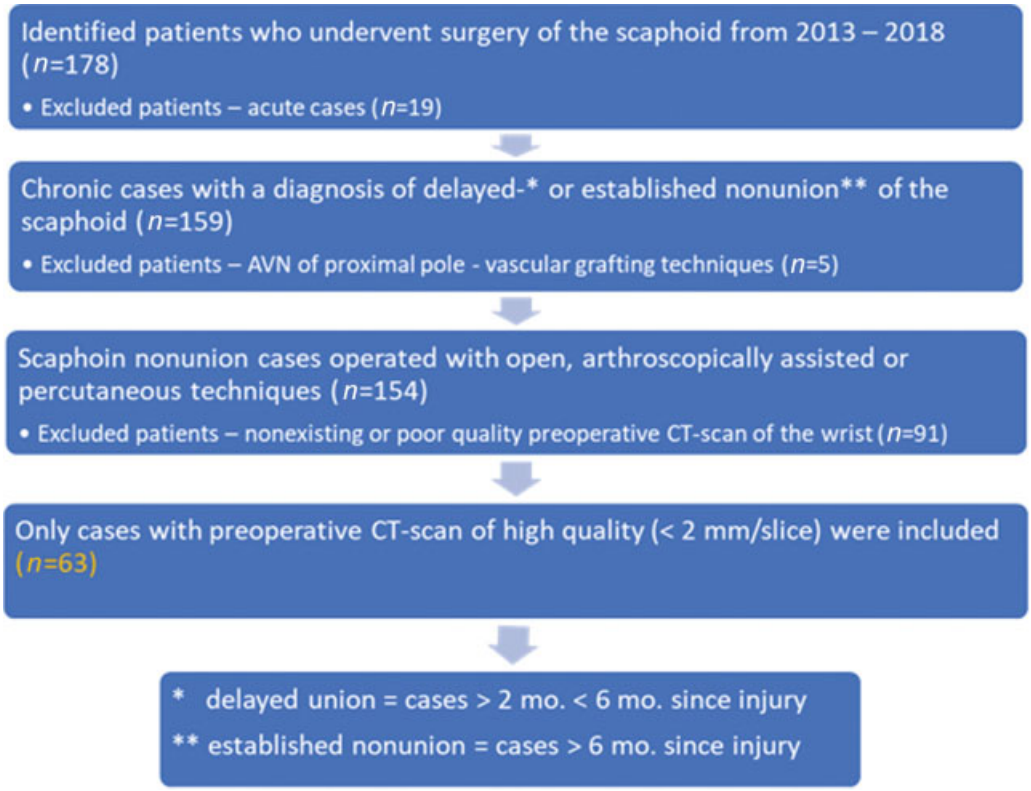

Fig. 1 Enrollment chart with inclusion/exclusion criteria for the study. CT, computed tomography.

Table 1 Patient demographics between different treatment groups, supplemental injury, comorbidity, and the postoperative union assessment

Patients' characteristics	Type of treatment			
	Open approach	Percutaneous	Arthroscopic	Total
No. of patients	49	6	8	($n = 63$)
Age (y): mean (range)	30.2 (16–72)	39.6 (20–66)	22.3 (16–32)	30.7 (16–72)
Gender: M/F	45/4	5/1	8/0	58/5
Right				27
Left				36
Dominant side				36
Preoperative treatment				
Conservative/surgery				20/0
Supplemental injury	8	1	0	9
Comorbidity (various)	12	0	0	12
Diabetes	1	0	0	1
Medication incl. steroids	10	0	0	10
Tobacco smoking	8	2	1	11
Assessment of union				
Clinically and radiographs	28	3	5	36
Clinically and CT scan	14	1	2	17
Clinically and radiographs and CT scan	5	2	1	8
Preoperatively	2	0	0	2

Abbreviations: CT, computed tomography.
Note: No major difference between groups concerning assessment method.

scaphoid proximal pole (►**Table 1**). Definition of the proximal- or distal pole was for practical reasons defined as the presence of the pseudoarthrosis line within the most proximal- or most distal 25% of the scaphoid bone. The measurements were performed on both coronal and sagittal CT scan series. This classification was performed by a single surgeon of the present study. Most of the patients ($n = 49$) were treated by open grafting techniques with either iliac bone graft, or bone graft taken from the ipsilateral distal radius. This leaves 14 patients who were treated with minimally invasive techniques, either percutaneously ($n = 6$), without grafting, or arthroscopically assisted bone grafting from distal radius ($n = 8$). ►**Table 1** shows patients demographics, major characteristics of the treatment groups, and the method of the union assessment. Thirty-two of the patients had developed nonunion of the scaphoid (>6 months postinjury), while 31 were in a stage of delayed union (2–6 mm postinjury) (►**Table 2**). Mean time from injury to surgery was 498 days (16 months) (range: 2 months–15 years).

The information on patient's gender, age, time from injury to surgery, smoking habits, medication, general health status, including information on chronic diseases as diabetes, alcohol habits, information of previous treatment, and the localization of the scaphoid nonunion was collected. Only a few of the patients, mostly in delayed union presentation, received conservative treatment with a short arm cast for their injury, before the referral to our institution. Vast majority of the patients interpreted their primary symptoms as a wrist sprain, and this was the major cause of the delay of both diagnostics and the treatment. None of the patients underwent any wrist surgical treatment prior to scaphoid nonunion surgery.

The Assessment of the CT Measurements

Five observers, tree orthopaedic surgeons, one orthopaedic resident, and one radiologist, independently analyzed the preoperative CT scans of the scaphoid bone. The CT scans were taken by Toshiba CT scanner (Toshiba, Aquilion One 320, Tokyo, Japan), reformatted by software using IMPAX Client 6.6.1.8006 software (AGFA Healthcare, Mortsel, Belgium). Three most used angulation measurements, dorsal cortical angle (DCA), lateral intrascaphoid angle (LISA), and the height-to-length (H/L) ratio were measured on CT scans multiplanar reconstruction (MPR) images, according to Bain et al.[40] Furthermore, measurements of the size of the cysts and displacement on both coronal and sagittal MPR images of the scaphoid nonunion site were taken. The measurement techniques used are shown on ►**Figs. 2** and **3**. Prior to beginning of this study, CT scan angulation measurements were performed by all observers, on three trial cases. Special emphasis was on LISA measurements, which several observers considered most difficult. Trial cases were not included in the study. Instead, they were chosen among those CT scans who were excluded from the study due to low-quality.

Table 2 The stage of the nonunion (time lapse from injury to surgery), and dispersion of cases with larger deformities (dislocation of ≥ 2 mm, LISA angle ≥ 45 degrees, DCA ≤ 110 degrees, H/L ratio ≥ 0.65, and presentation of bony cyst within the nonunion site ≥ 5 mm), related to different treatment groups, and stages of the scaphoid nonunion

	Open ($n = 49$)	Percutaneous ($n = 6$)	Arthroscopic ($n = 8$)	Delayed union (< 6 mo)	Nonunion (> 6 mo)
Time since injury (stage of the nonunion) (number of cases)		Percentage (%) related to treatment group			Percentage (%) related to stage of the nonunion group
Delayed union (< 6 mo)	21 (43%)	6 (100%)	4 (50%)	$n = 31$	
Nonunion (> 6 mo)	28 (57%)	0 (0%)	4 (50%)		$n = 32$
Dislocation (no. of cases)					
≥ 2 mm	32 (65%)	3 (50%)	4 (50%)	22 (71%)	17 (53%)
Humpback deformity (no. of cases)					
LISA angle ≥ 45 degrees	5 (10%)	1 (17%)	2 (25%)[a]	3 (10%)	5 (16%)
DCA ≤ 110 degrees	29 (59%)	4 (75%)[a]	4 (50%)	18 (58%)	18 (56%)
H/L ratio ≥ 0.65	38 (78%)	6 (100%)[a]	5 (63%)	24 (77%)	25 (78%)
Bony cysts (no. of cases)					
≥ 5 mm	36 (73%)	4 (66%)	4 (50%)	18 (58%)	26 (81%)

Abbreviations: DCA, dorsal cortical angle; H/L, height-to-length; LISA, lateral intrascaphoid angle.
[a]Note the higher presence of cases with ISA angle ≥ 45 degrees in the arthroscopic treatment group, and accordingly higher DCA ≤ 110 degrees, and H/L ratio ≥ 0.65 in the percutaneous treatment group.

The Postoperative Regime and the Assessment of the Union

The postoperative regiments were similar for the different surgical options, comprising immobilization with a thumb/wrist splint, or removable orthosis for 2 to 6 weeks. Patients were assessed clinically and radiographically at the follow-up on the 6th postoperative week. If union could not be confirmed, the immobilization continued for intervals of 2 to 4 weeks until union was radiologically and clinically evident. If the union could not be established within the first 6 postoperative months, further follow-ups and radiological investigations were booked in accordance with the

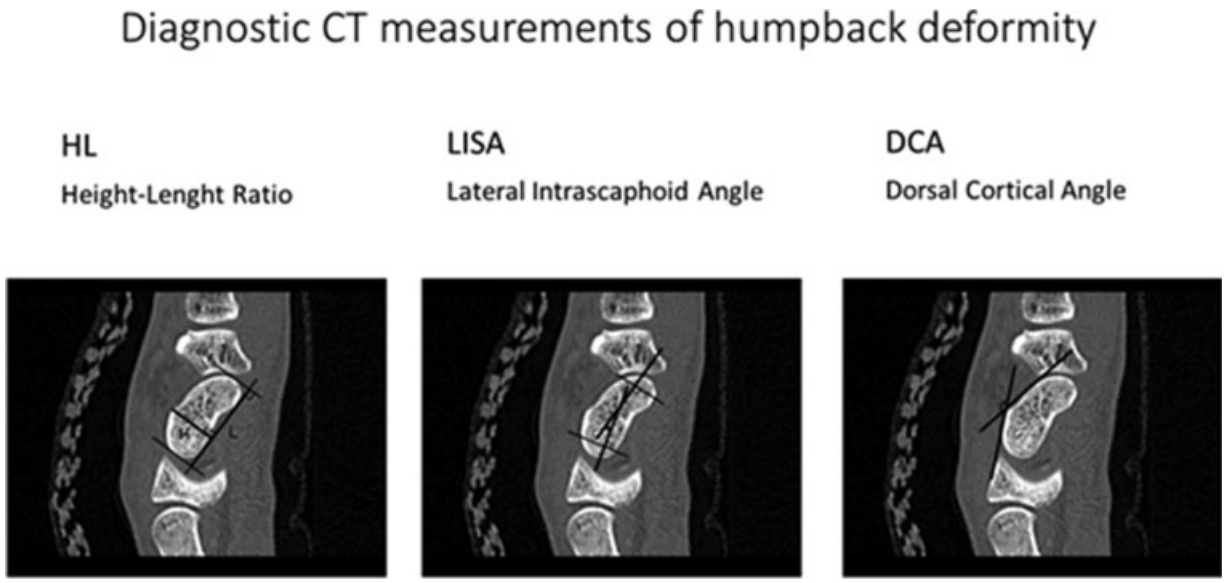

Fig. 2 Display of computed tomography scan angulation measurement lines (black) for height-to-length (H/L) ratio, lateral intrascaphoid angle (LISA), and dorsal cortical angle (DCA). Image courtesy: Guldbrandsen et al.[55]

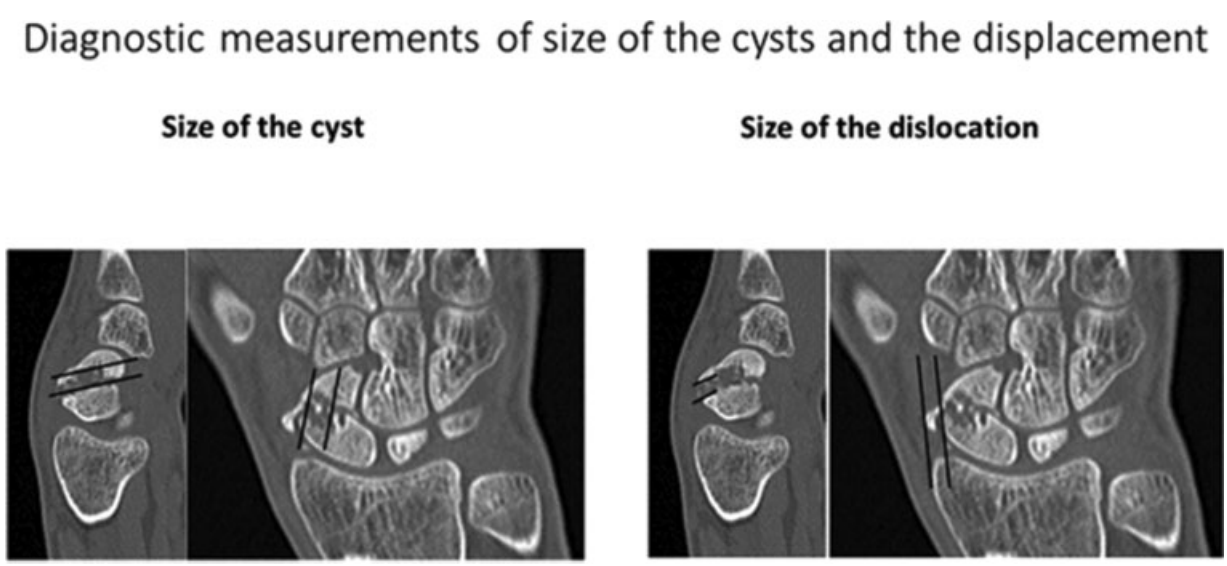

Fig. 3 Display of the measurements of bony cysts and displacements on both coronal and sagittal computed tomography scan series. The measures were taken between the drawn lines (black), and only the largest recorded value was used.

patients' ability to visit the outpatient clinic. Thus, the healing after surgery was defined either by CT scan or by conventional X-ray and a presence of pain-free wrist at the clinical examination (►**Table 1**). The main criteria for union were thus the presence of bridging trabecula on > 50% of scaphoid-axis CT reconstruction scans, in both the coronal and sagittal planes of the scaphoid, according to Singh et al.[41] The collection of union-time data was performed by an independent reviewer, not clinically related to any of the present cases.

Statistics

The analysis of data was performed by SAS Statistical Analysis Software package, using multiple linear logistic regression (two-way analysis of variance [ANOVA]), generalized linear modelling, chi-squared test, and Pearson's correlation analysis. Mean and standard deviations (SD) were used for interval variables, while median and interquartile range were used for ordinal variables. Throughout conventional level of significance (0.05) was applied and the results with $p < 0.05$ were consequently considered statistically significant. *p*-Values and confidence intervals (CI) were calculated everywhere as controlled measures, using adequate controlling variables. Multivariable adjustments were made in relation to identified confounders (age, tobacco smoking, alcohol drinking habits, supplemental injuries, medication, and comorbidity). Expected levels of object variables were compared with fixed (mean) values of confounding variables, assuming simple linear relations, and using ordinary ANOVA practices. This analysis was repeated for the subgroups of patients with greater angulations, larger dislocations, and bony cysts, thus assuming these being in the greater risk for poorer union.

Interrater reliability for CT-scan measurements between five observers was calculated under two-way of ANOVA using the intraclass correlation coefficient (ICC). ICC < 0.49 was defined as poor, 0.50–0.74 as moderate, 0.75–0.89 as good, and >0.90 as excellent.[42]

Results

All the patients but one, who was treated with Kirschner wires (K-wires), were treated by Acutrak headless, fully threaded compression screw system (Acumed; Hillsboro, OR). Open surgery was the treatment of choice in 49 patients, 8 patients were treated arthroscopically, and 6 patients with delayed union were operated with percutaneous method. The follow-up was 11 months (mean), (range: 3–43 months). Fifty-six patients had a minimum follow-up of 6 months after surgery. Remaining 7 patients, all high school students of age < 19 years, were absent from the regular 6 months follow-up.

CT Measurements as Predictive Values for Union Outcomes

Mean dislocation, measured on preoperative CT scan, was 2.75 (SD: 1.65) mm, mean LISA angle was 33.2 degrees (SD: 10.2), and DCA (mean) was 107.2 degrees (SD: 16). H/L ratio (mean) was 0.69 (SD: 0.08) and the size of the cysts was distributed by following categories: no cysts (cat. 0) $n = 8$; cysts < 5 mm (cat. 1) $n = 32$; cysts > 5 mm (cat. 2) $n = 22$; cysts > 10 mm (cat. 3) $n = 1$. Distribution of the dislocation, presentation of humpback deformity and bony cysts within different treatment groups, and time stages of the nonunion are presented in ►**Table 2**. For better understanding, and disclosure of differences between the groups and nonunion stages, cases with larger deformities are emphasized: (cases with dislocation of ≥ 2 mm, LISA angle ≥ 45 degrees, DCA angle ≤ 110 degrees, H/L ratio ≥ 0.65, and presentation of bony cyst within the nonunion site ≥ 5 mm). Some of these values are usually used in the literature with an assumption that they could eventually correlate with a higher risk of poor outcome.

Overall union rate was 86% (54 out of 63) and was achieved after mean 84 days (SD: 25). The union rate and time to union were not associated with the degree of the

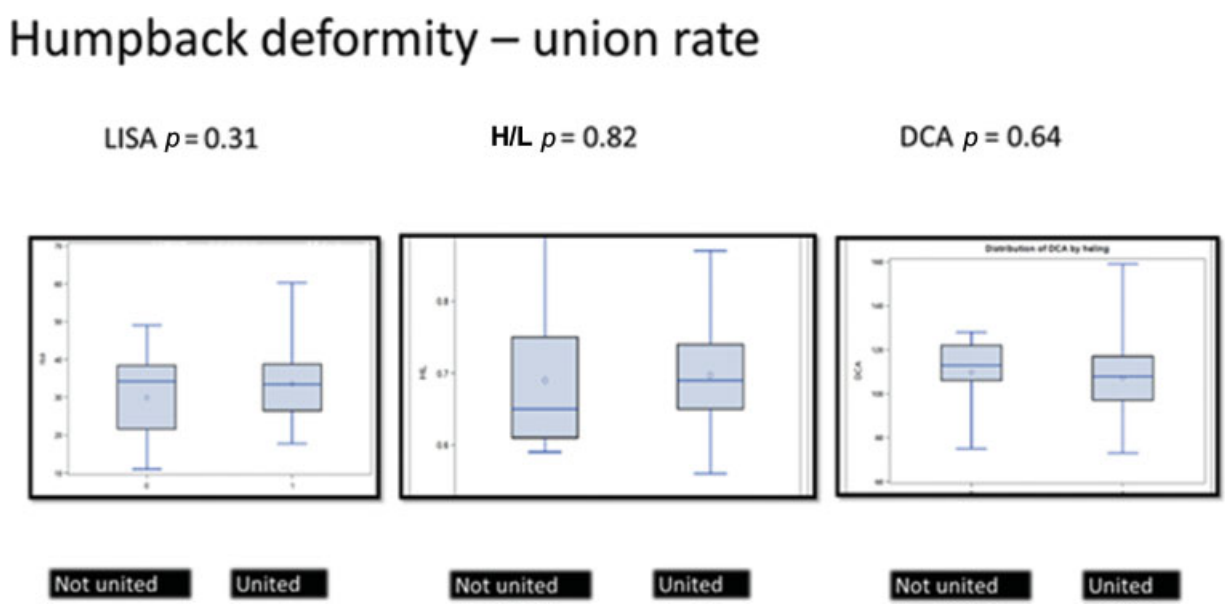

Fig. 4 Distribution of the union rate, and different angulation deformity measurements (LISA, HL, DCA) in united and not united patients, presented in box plot diagrams. DCA, dorsal cortical angle; H/L, height-to-length; LISA, lateral intrascaphoid angle.

humpback deformity (►**Figs. 4** and **5**), size of the cysts, or displacement of the nonunion. Localization of the nonunion had no impact on union rate- or time, in general. However, larger displacement and the localization of the nonunion at the scaphoid waist showed significant influence on the union rate (►**Fig. 6**). Displacement in patients who united after surgery was 2.7 mm (95% CI: 1.5–3.7), and in the group who did not unite was 4.2 mm (95% CI: 2.9–5.7; $p = 0.048$). Time from injury to surgery was significantly correlated with time to union (►**Fig. 7**), but not associated with the union rate ($p = 0.05$, $p = 0.4$, respectively).

Union Outcome in Relation to Localization, Type of the Nonunion, and Operative- and Bone-Grafting Techniques

Localization of the nonunion had no impact on union rate- or time. As far as operative technique and union rate are concerned, all patients treated with open surgery and a structural graft from the iliac crest united. Eighty percent of patients treated with open surgery and cancellous bone grafting achieved union. All patients with delayed union treated percutaneously united, while 88% of patients treated for nonunion with arthroscopically assisted bone grafting achieved union.

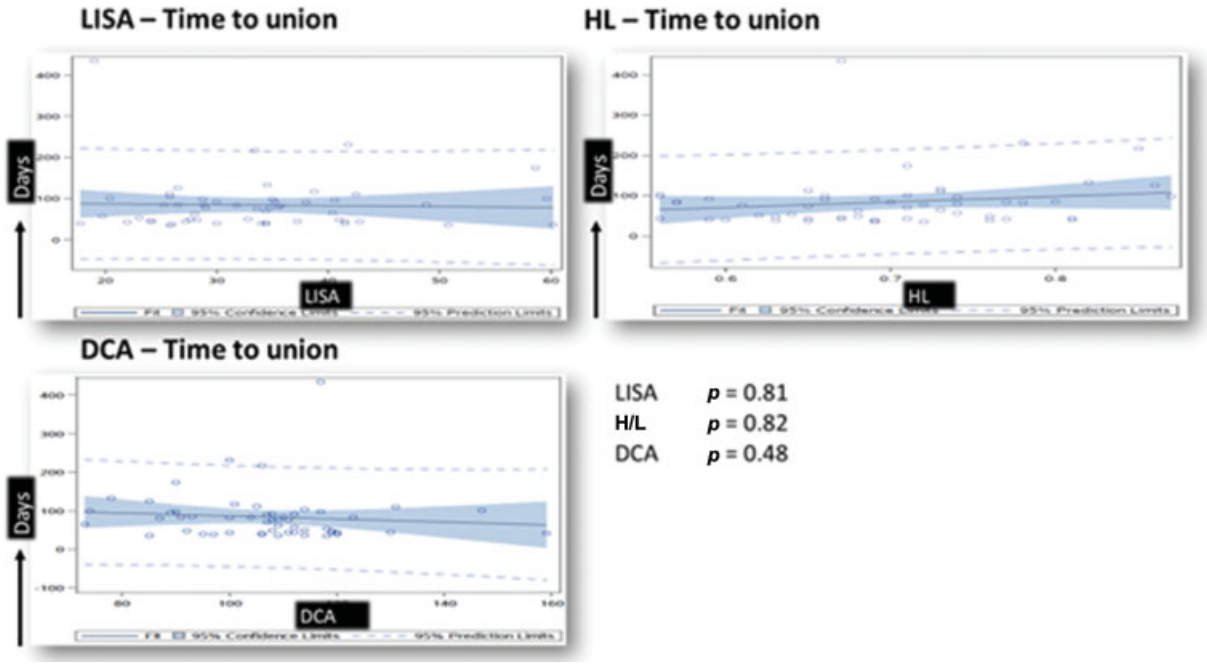

Fig. 5 Time to union after surgery assessment in different angulation deformity measurements (LISA, HL, DCA), showing flat regression fitting lines in diagrams, interpreted as no correlation. DCA, dorsal cortical angle; H/L, height-to-length; LISA, lateral intrascaphoid angle.

Fig. 6 Dislocation measurements in millimeters and the influence on the union rate, for all nonunion cases, and for the scaphoid waist cases.

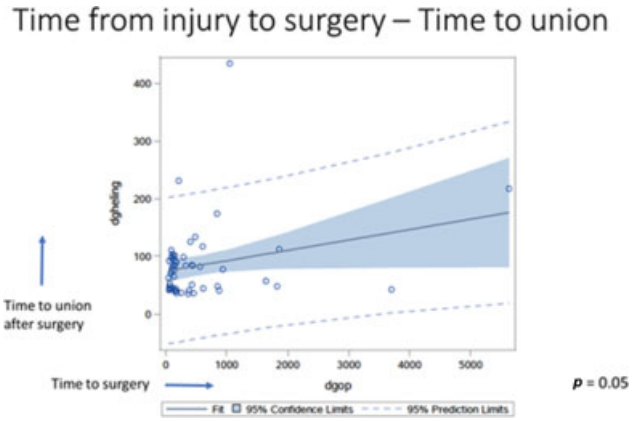

Fig. 7 Time lapse since injury to the surgery and its influence on union time showed as a regression (fitting) line with a raising curve, meaning longer time from injury to surgery—longer time to union. (x axes = days from injury to surgery, y axes = days from surgery to union).

Concerning time to union, in relation to operative technique, patients treated arthroscopically ($n = 8$) achieved faster healing (mean: 42 days) (SD: 4.8), as compared with patients treated by open techniques ($n = 49$; mean: 92 days; SD: 70.9), with 95% CI for the groups: (37.91–46.09) and (69.73–114.46), respectively.

Concerning type of the graft, patients treated with the structural corticocancellous graft united at mean 99 days (SD: 66.4). Patients treated with cancellous-only graft taken from iliac crest/distal radius showed union at mean 85/88 days (SD: 22.2/SD: 98), respectively. Further elaboration on union rate with relation to type of graft used in surgery or with relation to localization of the nonunion is shown in ►**Table 3**.

Union rate and time were not influenced by smoking habits ($p = 0.12$, $p = 0.44$), presence of diabetes ($p = 0.68$, $p = 0.83$), or other chronic disease ($p = 0.77$, $p = 0.70$), respectively. Corresponding nonsignificant values ($p > 0.05$) in relation to union rate and time were calculated for patient's age, previous treatment, presence of concomitant injury, and usage of heavy medication.

Reliability Results

The results of interrater reliability calculation (ICC) for CT scan measurements between five observers were LISA: 0.92; H/L ratio: 0.73; DCA: 0.65; size of cysts: 0.61; and displacement in millimeters: 0.24, respectively, showing the best correlations among observers for ISA angle measurements, and lowest correlation among observers for the measurements of displacement.

Complications and Revisions

Four patients had to be operated for the removal of the hardware, three for removal of the Acutrak compression screws, caused by prominence of the screws into either trapezium, or radius bone, and one for the removal of the K-wires. Of those nine patients who did not achieve union, one patient, 18-year-old man, presented with a delayed union of the scaphoid, and treated with cancellous graft from iliac bone, underwent reoperation using new iliac bone cancellous regrafting technique, accompanied by use of Nanostim Synthetic Bone Paste, hydroxyapatite-based bone graft substitute (Medtronic, Memphis, TN). Union occurred 4 months after revision surgery. Two patients, one 33-year-old man, another a 21-year-old man, both with proximal pole scaphoid nonunion and primarily treated using cancellous bone graft taken from distal radius without achieved union, were both successfully treated with an

Table 3 Localization of the scaphoid nonunion among patients related to the treatment- and grafting method. Cases not united after surgery, and their dispersion in different groups

Patients' characteristics ($n = 63$) *Marked cases in cursive parenthesis = not united after surgical treatment ($n = 9$)*	**Type of treatment**				
	Open ($n = 49$)	**Percutaneous ($n = 6$)**	**Arthroscopic ($n = 8$)**		
Localization of the nonunion		Percentage related to treatment group		Percentage of not united cases related to localization of the nonunion ($p = 0.44$)	Union time related to localization (days) ($p = 0.72$)
Distal ($n = 2$)	2 (4%)	0	0	(0%)	83.5
Waist ($n = 49$)	41 (84%) (5)	4 (66%)	4 (50%) (1)	(6)/49 (12%)	87.1
Proximal ($n = 12$)	6 (12%) (3)	2 (33%)	4 (50%)	(3)/12 (25%)	68.0
Type of the graft *Marked cases in cursive parenthesis = not united ($n = 9$)*				Percentage of not united cases and type of the graft ($p = 0.34$)	Union time related to type of the graft (d) *($p = 0.38$)*
Structural from iliac bone ($n = 15$)	15	0	0	(0)/15 (0%)	99.6
Cancellous from iliac bone ($n = 15$)	15 (3)	0	0	(3)/15 (20%)	85.4
Cancellous from radius ($n = 29$)	21 (4)	0	8 (1)	(5)/29 (17%)	88.4
No graft ($n = 7$)	1 (1)	6	0	(1)/7 (14%)	56.8
Not united cases (number of patients for each group and total)	(8)	(0)	(1)	(9)	

Note: Union time for different localizations and for different grafting techniques.

Adaptive Proximal Scaphoid Implant, pyrocarbon spacer (Tornier/Wright Medical, Montbonnot-Saint-Martin, France). Their treatment was completed satisfactorily 6 months after this revision procedure. Five patients, among these, four men, two heavy tobacco smokers, and one with nonunion of the proximal pole, one originally presented with a delayed union, and a 70-year-old woman with concomitant diseases, rejected revision surgery despite failure to unite after primary procedure. Their decision was caused by lack of symptoms that will justify revision procedure. Finally, a 21-year-old male patient, originally presented with a delayed nonunion of the scaphoid with some residual pain, and with CT scan at 1-year follow-up showing partial union, underwent revision surgery 21 months after primary procedure. The compression screw was removed, nonunion site was found perioperatively totally united, and the patient was thereafter pain free.

Discussion

CT scan is reported as a more useful tool than plain radiographs in assessing both displacement, and angulation measurements, and evaluating the union.[43] Three mostly used angulation measurements on preoperative CT scans were used as interpretation of the humpback deformity. The LISA, originally described by Amadio et al,[33] and modified by Bain et al,[40] has in some studies previously been suggested as a good predictor of the functional outcome, but poor in others.[44–47] Although LISA had a poor inter- and intrarater reliability, it is still commonly utilized.[40] While H/L ratio seems to have a high intra- and interrater reliability,[48,49] it is probably a poor predictor of functional outcome.[48] DCA is perhaps less prone to observer bias than LISA, but is probably a poorer predictor of functional outcome.[50,51]

Some studies[52] suggest further investigation on the utility and the application of the angulation measurements in a daily clinical practice. Since the angle measurements are not useful as a predictor of functional outcome, the question remains to be answered if they can be useful as a predictor of the union. Despite common opinion of greater humpback deformity and bigger cyst formations stands for poorer or slower union after scaphoid fractures, derived from study of Grewal et al[5] on acute cases, results in our study on scaphoid nonunion cases could not support these findings. The size of

bony cysts or the angle of present humpback deformity did not influence, neither union rate, nor union time in our series. However, the greater dislocation at the scaphoid waist gave lower union rate in our series; thus, the dislocation remains one of the major risk factors concerning the union rate at scaphoid waist fractures, with late presentation (delayed- or nonunion). Meantime, if the dislocation measurements are to be used as a prediction tool, a more standardized approach needs to be used to increase the reliability of the measurements among observers.

Different angulation measurements of humpback deformity of the scaphoid may still be used as a tool in the selection process of the right surgical method, for each case presented. However, further studies on this topic are needed, as cases with different nonunion patterns may need different treatment solutions, and making the right treatment algorithm is the research task for the future.

Several authors have reported tobacco use as a risk factor for the failure of union.[15,47,53] However, this was not the finding of our study, even though 17% of our patients were tobacco smokers. In the study of Schuind et al,[47] the authors analyzed prognostic factors in the curative treatment of scaphoid nonunion in a literature review. They found tobacco smoking, the time lapse since the fracture, and the presence of AVN the main negative prognostic factors for the union rate. Vascularized bone grafts were not found superior to conventional bone grafts. Tambe et al[11] compared the use of iliac structural bone graft with the graft taken from ipsilateral distal radius bone, and found similar union rate of 87%/89%, respectively. Our findings, besides the results in tobacco smokers, are in accordance with the results in both studies, with similar overall union rate of 86%, and no significant difference between two open surgical techniques, neither concerning union rate nor union time.

The choice of surgical technique may possibly influence the union. Even though treatment groups were different in proportions, no difference was found in severity factors between groups. However, all patients treated by percutaneous technique were delayed unions (<6 months since injury), thus being less exposed to poorer union outcome. In our series, more cases with greater gaps (dislocations) and larger cysts were treated by open bone grafting, while there were more cases with proportionally larger humpback deformities in the groups treated with minimally invasive approach. However, the feasibility of arthroscopically assisted bone grafting technique on equally demanding cases remains to be proved by future studies, with larger series, preferably in a design with a control group. Reversely, half of the cases with a nonunion placed on the proximal pole of the scaphoid were treated successfully with minimal invasive surgery, with or without bone grafting techniques, thus showing promising results.

Arthroscopically assisted bone grafting showed promising results in our cohort, although results may have been affected by younger age of the patients in this group. However, the age was not confirmed as confounding factor in this study. This is in accordance with other studies,[17–23] although a single comparative study between open and arthroscopic methods[54] showed significantly higher operative time for this, technically more demanding procedure. Even though open grafting restored carpal alignment superiorly than arthroscopic technique, union rate and functional results between groups were similar. The results of union time between these techniques were not presented.

Time from injury to surgery, as a prediction factor for the union, is partially confirmed in our series, as longer time from the fracture occurrence to the surgical procedure was associated with significantly longer union time, but not with lower union rate.

The union rate and time to union for the scaphoid nonunion at the localization of the proximal pole did not differ significantly from scaphoid waste in our cohort (►**Table 3**). One possible explanation for that outcome is that almost the half of the patients with a proximal pole nonunion (6/12) were treated with the minimally invasive surgical methods, arthroscopic bone grafting ($n=4$), or percutaneous technique ($n=2$), thus minimizing the surgical trauma in the area of poor vascularization.

The results of interrater reliability of various angulation measurements in our study showed unexpectedly higher correlation between observers for measurements of LISA, which was supposed to be the most difficult of all measurements. In contrast, defining the size of displacement showed the poorest reliability. The reasons for such discrepancies from findings of other studies could be possibly explained by our preagreed consistency of LISA measurements. A standardization of dislocation measurements is probably needed.

Limitations

Our study had certain limitations. First, this was retrospective study, and the criteria for the choice of the treatment method were unclear. Besides, we had to exclude 91 patients from this study, mostly due to lack of the preoperative CT scans, especially in cases referred from other centers, presented with only plain radiographs, or only magnetic resonance imaging scans, making the participation in the study based on preoperative CT scans impossible. Poor CT scanning techniques were the problem, particularly at the beginning of inclusion period, when there were many CT scans with poor technical quality due to too large gap between slides.

In the assessment of the union, after the surgery, if there was any doubt about the union on the conventional radiographs, CT scan was used, but the results would probably be even more accurate if also the union of all the patients involved in the study was assessed with CT scans, postoperatively. However, concerns about patients having union assessed by additional CT scan, possibly representing those with worse prognosis, have thus been avoided as there were no differences in assessment methods, between the groups (►**Table 1**).

In our study, only half of the cases were scaphoid nonunion (> 6 months), leading one on the thoughts that patients with delayed union (< 6 months) would have united anyway. Indeed, the results concerning the time lapse from injury to surgery showing significantly longer time to union as time toward surgery was longer confirm only partially this

theory. Looking into differences between stages of the nonunion (►**Table 2**), only larger presence of bony cysts in nonunion group $\geq$ 6 months was accounted, while humpback deformity was similar between groups. The presence of the gaps of $\geq$ 2mm at the nonunion site was unexpectedly larger in the delayed nonunion group than in the group of more chronic cases ($\geq$ 6 months) (►**Table 2**). However, the results of union rate between cases with a delayed union and nonunion longer than 6 months did not differ in our series.

This study did not include functional outcome of the patients, out of above-mentioned reasons. Functional outcome at the short, or mid-term follow-up time does not seem to be dependable, neither of scaphoid malformation before surgery,[44,48,51] nor choice of the treatment method.[54] A study is needed to enlighten the eventual difference on the occurrence of posttraumatic osteoarthritis after different surgical methods, and the implication on the long-term functional outcome. A larger, comparative, preferably randomized controlled trail study between different treatment methods is desirable.

Conclusion

The degree of humpback deformity and the size of cysts along the fracture line of scaphoid nonunion have no predictive value for the surgical result. However, greater dislocation of the fragments at the scaphoid waist showed lower union rate. Time to healing following surgery is mostly influenced by the time from injury to the surgical treatment and may be influenced by the choice of the surgical technique. The variation in interrater reliability calculations among observers for different CT measurements is still disputable, but seems to be influenced if the consensus among observers is established beforehand.

Note

This study was performed at Herlev/Gentofte Copenhagen University Hospital, Hand Surgery Unit.

Ethical Approval

Ethical committee approval for retrospective studies is not necessary in Denmark. This study acquired necessary approval by the Danish Patient Safety Authority, case number 3–3013–2815/1.

Conflict of Interest

None declared.

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